MATRIX ELEMENT MAGNETIC PAVEMENT MARKER AND METHOD OF MAKING SAME

Field of the Invention

The present invention relates to magnetic pavement markers and a method of making the same, and more particularly, to a system for guiding vehicles and other mobile objects along a roadway, warehouse floor, and the like.

Background of the Invention

Safer, more efficient and more accessible transit for citizens is a high priority. Public service workers, public transit vehicles and emergency vehicles must have the capability to move more rapidly and safely on roadways in a variety of weather conditions.

Inclement weather and even blinding sunlight or oncoming traffic light present special problems both for existing travel systems and for guidance systems that offer lateral vehicle control. Snowy conditions, fog, heavy rain, blowing dust and smoke are examples of challenges to vehicle drivers. Snowy weather presents particularly challenging driving conditions to snowplow drivers trying to clear lanes in blowing snow or when lane markers are obstructed by snow. Furthermore, reduced visibility brought by blowing snow has caused numerous tragic accidents when automobile drivers have rear-ended snowplows traveling slower than surrounding traffic. Winter weather will continue to challenge any intelligent transportation system (ITS) in which vehicles move at faster speeds and closer together on more crowded roadways.

In addition to vehicles, other mobile objects such as farm animals, pets, fire fighters, visually impaired pedestrians, and the like may also benefit from control and/or guidance systems. Mobile robots equipped with magnetic sensors may be guided and/or controlled as they move on their path, for example, along an industrial assembly line. Perimeter and boundary awareness systems can be used for pet containment systems. Additionally, games frequently require defined boundaries, such as foul territory in baseball and out of bounds in soccer, and it is frequently desired that toys and sporting equipment emit audible signals when crossing a designated line.

Several alternate methods for sensing the lateral position of a vehicle on a roadway are known. One option involves the use of visible signs or markings and optical sensors. A system that relies on optical sensors can be obscured by dirt, ice, or snow, and visibility can be impaired by fog, blowing snow, blowing dust, and the like. Furthermore, for night usage, a considerable amount of energy is expended, either to illuminate the signs or to emit a beam from the sensor.

Another approach is the use of radar reflective markers with a radar ranging system on the vehicle. Both the markers and the radar detection systems are expensive in comparison with magnetic systems. In addition, metallic radar reflective markers embedded in the roadway are likely to have durability and corrosion problems.

A magnetic system is not adversely affected by weather conditions and does not require expensive video or other radio frequency equipment. A magnetic system's operating costs remain low since the marker is passive (no power is required to make a magnetic marker

function). Some magnetic markers can last the life of the roadway (typical roadways have life spans of six to eight years) and may even be reprogrammed while still a part of the roadway.

One magnetic marking system includes a series of magnetic "nails" embedded in the roadway. Since the field strength decreases as the cube of the distance from such a dipolar magnetic field source, the "nails" have to be fairly closely spaced to produce a useful signal. Material costs would be high if the most powerful rare earth magnets were used to minimize the size and maximize the spacing. Boring holes in the roadway and using rigid nails may also lead to stress concentration and premature pavement failure, which may be exacerbated by corrosion of nails. The use of simple ferrous metal spikes would not provide the alternating signal desirable for effectively separating the position signal from noise.

Another magnetic marking system employs a magnetic paint to produce magnetic stripes on the roadway. A sufficiently strong magnetic signal is difficult to obtain with the typical thickness of paint layers. If the thickness of the paint is built up to obtain a good magnetic signal, the paint durability can be reduced. The paint stripe can be magnetized only after it has dried. A specially designed magnetizing fixture would have to be driven along the strip. Since limitations in the magnetic field produced by such a fixture, the coercivity of the magnetic material would likely be limited to about 1000 oersteds, making it susceptible to erasure.

Some previously known magnetic guidance systems have employed materials embedded within a roadway, such as disclosed in U.S. Patent Nos. 3,609,678 and 3,714,625. The polymer-based

magnetic materials disclosed are resilient and flexible, such as nitrile and silicone rubber, and plasticized PVC. Resilient refers to recovering to substantially the original shape after removal of a deformation force. The '678 patent discloses, in one embodiment, a polymeric magnetic tape or sheet that is "either inserted edgewise in a narrow channel or slot or laid flat in a more shallow channel cut in the roadway." (col. 3, lines 4-6). This patent further states that magnets may also be embedded within the pavement of the roadway instead of in an open channel. (col. 3, lines 31-32). A flux sensor is mounted on a vehicle that travels over the roadway The sensor can generate an electric signal in response to the magnetic medium if the magnetic field is sufficiently strong to be sensed. The '678 patent discloses that the intensity of the magnetic field at the surface of the roadway should be at least 2 gauss, preferably at least 10 gauss, and more preferably at least 100 gauss, to provide a strong signal even when road conditions are less than optimal. (col. 4, line 75 through col. 5, line 6).

Conventional conformable non-magnetic pavement marking sheet materials are known in the art and typically comprise a polymeric material, such as one that could be crosslinked to form an elastomer, but which is not crosslinked in the sheet material and thereby provides desired viscoelastic properties. Conformable refers to being capable of being deformed under a loading force and retaining a substantial part of that deformation after removal of a loading force. Illustrative examples of conformable non-magnetic pavement markings include U.S. Patent No. 4,490,432, U.S. Patent No. 5,316,406, U.S. Patent No. 4,069,281, and U.S. Patent No. 5, 194,113.

Summary of the Invention

The present invention is directed to a magnetic pavement marker having an array of magnetic pavement elements interconnected by a removable or frangible carrier web that is conformable and that minimizes unnecessary materials, improves tamping efficiency and isolates adjacent magnetic pavement markers. Various methods of making the array of magnetic pavement elements are also disclosed. The present invention is also directed to a method of applying the present array of magnetic pavement elements onto a pavement surface.

The present magnetic pavement marker uses less material than conventional magnetic pavement markers because the conformance layer is substantially eliminated. The tamping efficiency is also improved by isolating the tamping force on the discrete magnetic pavement elements. In particular, the magnetic pavement elements act as force concentrators that direct applied tamping forces to create an enhanced bond of the marker material to the pavement surface.

In one embodiment, the array of discrete, magnetic pavement elements are substantially not interconnected, so that the delamination of a single pavement element does not adversely effect adjacent magnetic pavement elements. In some embodiments, the carrier web is sufficiently conformable that movement of an individual magnetic pavement markers does not adversely affect adjacent magnetic pavement elements.

In one embodiment the method of making a magnetic pavement marker includes forming an array of magnetic pavement elements, typically arranged in a desired predefined pattern, interconnected by a carrier

web. A frangible connection is formed between the magnetic pavement elements and the carrier web.

The step of forming the magnetic pavement elements interconnected by a carrier web can be performed by integrally forming the magnetic pavement elements and the carrier web, bonding the magnetic pavement elements to the carrier web, or bonding the carrier web to an upper surface of the magnetic pavement elements. The step of forming the frangible connection between the magnetic pavement elements and the carrier web can comprise partially severing the carrier web around a single magnetic pavement element or around groups of the elements.

In one embodiment, the magnetic pavement elements comprise magnetic particles distributed in a binder. The particles can be oriented to product a magnetic field. Additionally, a polarity can be induced in the magnetic pavement elements. The magnetic pavement elements can be constructed of conformable polymeric materials or non-conformable magnetic materials. The magnetic pavement elements may be a variety of shapes, such as a rope, a sheet, a perforated article, etc. The shape is dictated largely by the specific use of the article. The magnetic pavement elements can be selected from a group consisting of polymer, ceramic, metal and metal alloy magnets.

The carrier web can be selected from a group consisting of a polymeric film, paper, a liner, a screen, a mat, a nonwoven web, an open scrim, or a film or nonwoven web of a water-soluble or water-dispersible polymeric material. After the array of magnetic pavement elements is applied to the pavement surface, the portion of the carrier web surrounding the magnetic pavement elements is removed, leaving an array of

discrete, magnetic pavement elements. The carrier web is conformable, typically preferably extensible.

In an alternate embodiment, the magnetic pavement markers includes magnetic pavement elements formed in a predefined pattern on a carrier web. The carrier web has frangible portions between adjacent magnetic pavement elements. The frangible portion is preferably capable of substantially deteriorating when exposed to roadway conditions for a short time. A pressure sensitive adhesive can be applied to the rear surfaces of the magnetic pavement elements and a release liner is applied over the adhesive. The carrier web serves to maintain the array of magnetic pavement elements in a predetermined configuration until they are applied to a pavement surface. The carrier web subsequently deteriorates, leaving an array of discrete magnetic pavement elements spaced in substantially the same configuration as on the carrier web.

In another embodiment, the magnetic pavement elements have a pressure sensitive adhesive on their bottom surfaces. The adhesive-coated bottom surfaces of the magnetic pavement elements are arranged in an array on a release liner. A carrier web is bonded to top portions of the magnetic pavement elements to maintain the spatial orientation of the array when the release liner is removed.

The present invention is also directed to a method of applying an array of magnetic pavement elements to a pavement surface. The release liner is removed from the array of magnetic pavement elements. An adhesive, such as a pressure sensitive adhesive, is interposed between the magnetic pavement elements and the pavement surface. The portion of the carrier web surrounding the magnetic pavement elements is removed

from the array. In another embodiment, the array of magnetic pavement elements are formed in a predetermined pattern on a conformable carrier web.

The present invention is also directed to a magnetic pavement article. An array of magnetic pavement elements in a predefined pattern is interconnected by a carrier web. A frangible connection is located between the magnetic pavement elements and the carrier web.

The array of magnetic pavement elements may be magnetized in a single pattern, but are preferably magnetized in a pattern to produce a readily-detectable alternating magnetic signal on the sensor. However, to convey more detailed information, the inventive articles may be magnetized ("encoded" or "written") in more complicated patterns, as found in bar codes, credit card strips, or magnetic tape recordings.

The magnetic pavement markers are unpowered, meaning that they do not require an outside power source either to send or receive a signal. In this regard, the present invention is distinguishable from powered embedded articles such as those that are typically used to determine whether a vehicle on a roadway is stopped at an intersection, such as at a red light. Embedded sensors of this type are further distinguishable from the present invention in that the former requires electrical power, whereas the latter is an unpowered magnetic field source. The unpowered magnetic pavement marker of the present invention also requires less installation time and less maintenance, cost nothing to operate, and may be used in remote locations where a power supply is not readily available. Thus, the unpowered magnetic pavement markers of this invention provide several advantages over conventional embedded powered articles.

Another embodiment of the invention is a guidance system for guiding vehicles or mobile objects traveling on a pavement surface. The guidance system provides information to a vehicle driver or to another mobile object or system and/or controlling a vehicle or mobile object. The magnetic pavement elements may be underlaid beneath an existing traffic-bearing structure or installed on a pavement surface. The discrete magnetic pavement elements are much less susceptible to damage by vehicular traffic or a mismatch of thermodynamic and mechanical properties between the pavement surface and the discrete magnetic pavement elements. In one embodiment, the system includes an array of magnetic pavement elements according to the present invention are bonded to the pavement surface and a sensor for passing over a array. The sensor is capable of detecting the magnetic signal of the array of magnetic pavement elements. The output of the sensor would optionally be a lateral offset signal. The output of the sensor may be used to control a vehicle and/or provide information to a driver via a display unit.

A method of providing a guidance system for a traffic-bearing structure is another aspect of the present invention. The invention may be used in conjunction with the magnetic guidance of a snow plow. It is important for a snow plow to be properly located on the traffic-bearing structure, so that inadvertent damage to curbs, roadside signs, mailboxes, and the like can be avoided. Because lane markers can be obscured by snow or ice on a road, a snow plow driver would benefit from having a magnetic guidance system of the type described, such that the snow plow remains on the traffic-bearing surface. The present invention may be particularly beneficial for guiding snow plows in

white-out (intense, blowing snow) conditions when visual guidance is limited. Other useful applications include an electronic "rumble strip" that would provide warning to a driver that the vehicle was approaching the edge of a traffic-bearing structure, or a school zone, bridge deck, curve in the traffic-bearing structure, or obscure traffic-bearing structure entrance or exit, and as a component of an automated highway system in which vehicles are automatically guided in assigned lanes.

As used herein,

"Conformable" refers to a carrier web that exhibits a low unload energy of less than 125 grams/centimeter (0.7 pounds/inch) and an inelastic deformation of greater than about 10%, preferably greater than 20%, more preferably not less than 30% at 25°C

"Frangible connection" refers to a connection between the carrier web and magnetic pavement elements (or in some embodiments a segment of the carrier web between a minor portion of the carrier web attached to a single pavement element and the remaining portion of the carrier web) that is easily broken or breakable after application of magnetic pavement elements to the road.

"Frangible portion" refers to a portion of the carrier web that is easily broken or breakable, e.g., that is biodegradable, water soluble, or otherwise capable of substantially deteriorating.

"Substantially deteriorating" refers to degradation and dissipation of the carrier web when exposed to a variety of environmental factors, such as abrasion, rain and impact from roadway traffic, to yield an array of discrete pavement elements.

Brief Description of the Drawing

Figure 1 is a cross-sectional view of an illustrative array of magnetic pavement markers according to the present invention.

Figure 2 is a cross-sectional view of the array of magnetic pavement markers of Figure 1 being applied to a pavement surface.

Figure 3 is a cross-sectional view of an alternate illustrative array of magnetic pavement markers according to the present invention.

Figure 4 is a cross-sectional view of the array of magnetic pavement markers of Figure 3 being applied to a pavement surface.

Figure 5 is a cross-sectional view of an alternate illustrative array of magnetic pavement markers having a top-mounted carrier web according to the present invention.

Figure 6 is a cross-sectional view of the array of magnetic pavement markers of Figure 5 being applied to a pavement surface.

Figure 7 is a cross-sectional view of an array of magnetic pavement markers of Figure 5 embedded in the pavement.

Figure 8 is a schematic illustration of an exemplary process for making magnetic pavement markers according to the present invention.

Figure 9 is a schematic illustration of an alternate illustrative process for making magnetic pavement markers according to the present invention.

Figure 10 is a schematic illustration of an alternate illustrative process for making magnetic pavement markers according to the present invention.

Figure 11 is a schematic illustration of an illustrative array of magnetic pavement markers according to the present invention.

Figure 12 is a schematic diagram of an inventive control and/or guidance system in accordance with the invention.

These figures, which are idealized, are not to scale and are intended to be non-limiting.

Detailed Description of Illustrative Embodiments of the Invention

Figure 1 is a side sectional view of a magnetic pavement marker having an array 20 of magnetic pavement elements in accordance with a first embodiment of the present invention. The array 20 includes a plurality of magnetic pavement elements 24 and an integrally formed carrier web 22. In the illustrated embodiment, the magnetic pavement elements 24 comprise a permanently magnetizable material 25 dispersed in a binder 27. An adhesive 26 is pattern coated to a bottom surface 28 of the magnetic pavement elements 24. The adhesive 26 may alternatively be coated across the entire surface of the carrier web 22 and the magnetic pavement elements 24 without being applied to the interstitial portions of web 22. In the embodiment illustrated in Figures 1 and 2, the magnetic pavement elements 24 and the carrier web 22 are formed from the same material.

A release liner 30 optionally extends across the adhesive 26 until the array 20 is ready for use, particularly in embodiments where the adhesive 26 is a pressure sensitive adhesives. Top surfaces 36 of the magnetic pavement elements 24 that may optionally include non-slip particles. The non-slip particles may be embedded in the magnetic pavement elements 24 or adhesively attached. A frangible connection 32 is formed around a perimeter of the magnetic pavement elements 24, typically by die cutting, so that the

carrier web 22 can be removed after installation. The frangible connection 32 preferably has sufficient strength to releasably connect the magnetic pavement elements 24 and carrier web 22 until the array 20 is applied to a pavement surface 42 (see Figure 2).

Figure 2 is a side sectional view of the array 20 of Figure 1 being applied to a pavement surface 42. The release liner 30 is removed and the array 20 is tamped to the pavement surface 42. The magnetic pavement elements 24 act as force concentrators to focus the tamping forces directly to the interface between the adhesive 26 and the pavement surface 42. In an embodiment where the adhesive 26 is coated across the entire surface of the carrier web 22, the magnetic pavement elements 24 minimize the tamping force applied to the carrier web 22.

The carrier web 22 that surrounds the magnetic pavement elements 24 is then removed or peeled-back from the array 20 by breaking the frangible connection 32. The resulting array of discrete, magnetic pavement elements 24 is arranged on the pavement surface 42 in substantially the same configuration maintained by the carrier web 22 in the array 20. The discrete pavement elements 24 are not interconnected by the web 22, so that the delamination of a single pavement element does not typically adversely affect adjacent pavement elements. The array 20 has a high degree of conformance to the surrounding pavement surface 42 and is better able to accommodate for mismatches of the thermodynamic and mechanical properties between the pavement surface 42 and the discrete magnetic pavement elements 24.

Figure 3 is a side sectional view of an alternate array 50 of magnetic pavement elements 52 bonded to a carrier web 54 by a variety of methods. An

adhesive 56 is applied to the entire lower surface 57 of the carrier web 54 or underneath the magnetic pavement elements 52. A release liner 58 is then applied to the adhesive 56 until the array 50 is ready for use. The carrier web 54 is conformable and frangible, preferably extensible. A nonexclusive list of carrier webs include polymeric films, paper, liners, screens, mats, nonwoven webs, and open scrims. In the embodiment of Figures 3 and 4, the magnetic pavement elements can be conformable or non-conformable magnets, including polymeric magnets, ceramic magnets, metal magnets and metal alloy magnets. The magnetic pavement elements 52 can optionally have a plurality of retroreflective beads 55 bonded thereto using an adhesive 59, such as disclosed in U.S. Patent No. 4,988,541 (Hedblom).

Figure 4 is a side sectional view of the array 50 of Figure 3 applied to a pavement surface 42. The release liner 58 is removed and the array 50 is tamped to the pavement surface 42. The carrier web 54 defines frangible portions 60 between adjacent pavement elements 52. The frangible portions 60 are preferably capable of substantially deteriorating when exposed to roadway conditions. As illustrated in Figure 4, the frangible portions 60 progressively deteriorates, leaving an array of discrete, magnetic pavement elements 52 having substantially the same pattern as on the carrier web 54 prior to application to the pavement surface 42. In an alternate embodiment, a series of slits 62 may optionally be formed around the perimeter of the pavement elements 52. The portions of the carrier web 54 surrounding the pavement elements may optionally be peeled-back or otherwise removed, such as shown in Figure 2.

In yet another embodiment, the carrier web 54 is conformable and extensible. The resulting array 50 of magnetic pavement elements 52 is arranged on the pavement surface 42 in substantially the same configuration maintained by the carrier web 54. Although the pavement elements 52 are interconnected by the portions 63 of the carrier web 54 (shown in dashed lines), the conformable and/or extensible carrier web 54 provides a high degree of conformance to the surrounding pavement surface 42 to accommodate for mismatches of the thermodynamic and mechanical properties between the pavement surface 42 and the elements 52.

Figure 5 is a side sectional view of an alternate array 100 of magnetic pavement elements 102 having an adhesive 104 on a bottom surface 106. The bottom surfaces 106 are arranged in an array on a release liner 108. A carrier web 110 is bonded to upper portions of the pavement elements 102, preferably by an adhesive, to maintain the spatial orientation of the array 100 when the release liner 108 is removed. In one embodiment, the adhesive used to bond the carrier web 110 to the pavement elements 102 has a lower peel strength than that of the adhesive 104 to bottom surface 106 or pavement surface 42. In another embodiment, the carrier web 110 is a biodegradable material, such as paper, or a film or nonwoven web of a water-soluble or water-dispersible polymeric material. In an alternate embodiment, the carrier web 110 can be a conformable and extensible material.

Figure 6 is a side sectional view of the array 100 of Figure 5 bonded to a pavement surface 42. In one embodiment, the release liner 108 is removed and the array 100 is tamped to the roadway surface 42. The carrier web 110 may then be removed, leaving an array

of pavement elements 102 on the pavement surface 42. Alternatively, the carrier web 110 may be allowed to substantially deteriorate. For the inlayed or underlayed embodiments discussed in connection with Figure 7, the carrier web 110 can optionally be a conformable and/or extensible material.

Figure 7 is an alternate embodiment in which magnetic pavement element 105 is underlaid and magnetic pavement element 107 is inlaid on an irregular pavement surface 42. The pavement surface 42 is a traffic-bearing structure such as base layer material, asphalt, gravel, concrete, cement, brick, wood, dirt, and/or clay. The array of magnetic pavement makers 100 is applied to the traffic-bearing structure 42 using one of the techniques disclosed above. Figure 7 shows the embodiment from Figure 6 for illustration purposes only. A pavement surface layer 109 is then applied to underlay/inlay the magnetic pavement elements 105, 107 within the pavement surface 42'. Underlaid is defined herein as being substantially surrounded by traffic-bearing structure material on all sides. Inlaid is defined herein as being at least partially surrounded by traffic-bearing structure material.

Other configurations for magnetic pavement markers are disclosed in U.S. Patent application No. 08/682,477 entitled Conformable Magnetic Articles for Use with Traffic Bearing Surfaces, Methods of Making Same, Systems Including Same, and Methods of Use and U.S. Patent No. 5,853,846, entitled Conformable Magnetic Articles Underlaid Beneath Traffic-Bearing Surfaces.

Adhesives known to be suitable for adhering articles to pavement surfaces include pressure sensitive adhesives, hot melt adhesives, hot melt pressure sensitive adhesives, contact bond cement,

thermoset adhesives and two-part epoxy adhesives. Some of these alternate adhesives are preferably interposed between the magnetic pavement markers and pavement surface 42 before bonding, rather than being coated on the array of magnetic pavement elements.

Figure 8 is a schematic illustration of one embodiment of an extrusion and embossing method 130 for manufacturing an array of magnetic pavement elements 132 according to the present invention. The expression magnetic pavement markers refers to both finished magnetic pavement markers or protrusions that can be subsequently processed to form a magnetic pavement marker, such as by orienting the magnetic particles 135 dispersed in a binder 137. The precursor sheeting 134 is the permanently magnetizable material embossed by an embossing roll 136 to form protrusions 144 of specified shapes and dimensions connected by a portion of the elastomeric sheeting 134 forming a base sheet 145.

An adhesive 138 is applied by a coating roll 140. A liner 142 is applied to the layer of adhesive 138. Alternatively, an assembly having a pressure sensitive adhesive 138 and liner 142 can be simultaneously laminated to the rear surface of the embossed magnetic pavement elements 132. The protrusions 144 formed on the embossed sheeting are then subjected to die cutting 146 to form a frangible connection 148 between the base sheet 145 and the protrusions 144. The magnetic pavement elements 132 can be applied to a pavement surface generally as illustrated in Figures 1 and 2.

The precursor sheeting 134 can be constructed from a variety of polymer based magnetic materials, such as disclosed in U.S. Patent No. 4,497,722 (Tsuchida et al.) Additional exemplary materials for forming the precursor sheeting 134 include

acrylonitrile-butadiene polymers, millable urethane polymers, neoprenes, and pavement marking materials disclosed in U.S. Patent Nos. 5,194,113 (Lasch et al.) and 5,127,973 (Sengupta et al.). Extender resins, inorganic fillers, such as silica, and reinforcements may also be included. The present array of magnetic pavement markers may be made using a variety of techniques, such as disclosed in U.S. Patent Nos. 4,388,359, 4,086,388, 4,988,541, and 5,194,113 (Lasch et al.).

Figure 9 is a schematic illustration of an alternate method 130′ for manufacturing an array of magnetic pavement elements 132′ according to the present invention. A series of die cuts 148′ are formed in a precursor sheeting 134′ of magnetic material by die cutting roll 136′ to form magnetic pavement elements 144′. The magnetic material can be conformable or non-conformable. The die cutting roll 136′ can be configured to cut a variety of patterns in the precursor sheeting 134′, such as the array illustrated in Figure 11. An adhesive 138′ is applied by a coating roll 140′. A conformable and/or extensible carrier web 142′ is applied to the layer of adhesive 138′.

In an embodiment in which the carrier web 142′ is conformable, a portion of the magnetic pavement elements 144′ are removed at station 146′ to form an array of magnetic pavement elements (see Figure 11). In an embodiment in which the carrier web 142′ is extensible, the carrier web 142′ can be biaxially stretched either before or during application to the pavement surface 42 to form a separation or gap between adjacent magnetic pavement elements 142′. The magnetic pavement elements can be applied to a pavement surface as discussed above.

Figure 10 is a schematic illustration of a cast and cure method according to the present invention. A polymeric material containing permanently magnetizable particles is extruded through a nozzle 150 from a screw-type extruder 152 to form a bank or tip of molten material 154 at an orifice between a steel forming drum 156 and a doctor drum 158. The circumferential surface of the drum 156 includes a series of cavities 160 which are the negative of the desired magnetic pavement elements 162. The molten material 154 fills the cavities 160 and is solidified to form a series of magnetic pavement elements 162 on an extensible carrier web 168. The extruder 152 preferably meters the quantity of polymeric material. Alternatively, a skiving tool such as a roller or a doctor blade can be used to scrape excess polymeric material from the roller 156 before the assembly 166 is brought into engagement with the roller 156. The polymeric material may be a thermoplastic polymer or a polymer that is subsequently cured to be a thermoset polymer. The polymeric material may also include inorganic fillers and reinforcements, such as glass beads, ceramic particles, micro-particles of glass or ceramic, and/or glass fiber strands.

Also entering the nip between the drums 156, 158 is an assembly 166 including a carrier web 168, a pressure sensitive adhesive 170, and a release liner 172. Upon being drawn into the nip containing the molten material 154, the carrier web 168 fuses and becomes inseparably united with the magnetic pavement elements 162. The forming drum 156 may optionally be heated to facilitate solidification of thermoset materials or cooled to facilitate curing thermoplastic materials.

The array 174 of magnetic pavement elements 162 is then subjected to die cutting 176 which at least partially severs the web 168 around the perimeter of the magnetic pavement elements 162. In one embodiment, the die cutting step 176 cuts through the carrier web 168, and optionally through the pressure sensitive adhesive 170, but not through the liner 172. The magnetic pavement elements may be subject to additional processing, such as the application of reflective material, either before or after the die cutting step.

In an alternate embodiment, the gap defined by the nip between the drums 156, 158 is increased so that the thin web of the thermoplastic composition is formed on the web 168 between the magnetic pavement elements 162, such as is illustrated in Figures 1 and 2. The subsequent die cutting step 176 preferably severs the thin web and carrier web 168 around the perimeter of the magnetic pavement elements 162. Alternate methods of forming magnetic pavement markers on a carrier web are disclosed in U.S. Patent Nos. 5,152,917 (Pieper et al.); 5,435,816 (Spurgeon et al.); and 5,500,273 (Holmes et al.).

If the material 154 is semi-liquid as it separates from the drum 156, the desired orientation of the magnetic particles may be produced by exposure to a permanent magnet or electromagnet 161. Mechanical working, such as that which occurs during extrusion or calendering, and/or externally applied fields will also promote orientation. Orientation enables one to obtain desired magnetic performance.

In an alternate embodiment, a rotary screen hot-melt pattern coater is used to coat a pattern corresponding to the magnetic pavement elements. The thermoplastic materials are first heated to a molten state and delivered to a die. The die coats the molten

material on a screen with a specified pattern and places the materials onto a first surface of a web or frangible carrier having adhesive and release liner on the second surface. The depth and definition of the pattern can be controlled by the die slot, speed of the belt, and/or viscosity of the thermoplastic material. The resulting assembly is then subjected to die cutting that at least partially severs the carrier web around the perimeter of the magnetic pavement elements. This embodiment of the present invention can be performed using a rotary screen hot-melt pattern coater available from May Coating Technologies, Inc. of White Bear Lake, Minnesota.

In yet another embodiment, insert molding (injection molding) techniques may be used for forming the magnetic pavement elements according to the present invention. The frangible carrier web can be inserted into the molds and the magnetic pavement elements can be molded on the top of the carrier web. Once the assembly is cooled, the magnetic pavement elements are ejected from the mold and the carrier web is indexed forward and the molding process repeated. Injection molding has the advantage that it is relatively fast and the technology is widely available. Other processing techniques applicable for making magnetic pavement markers according to the present invention are disclosed in U.S. Patent Nos. 5,201,916 (Berg et al.), 5,304,331 (Leonard et al.), and commonly assigned U.S. Patent application entitled Matrix Element Pavement Marker and Method of Making Same (Attorney Docket No. 53325USA3A), filed on the same date herewith.

Figure 11 illustrates an exemplary array 210 of magnetic pavement elements 212, 214 on a carrier web 216 in accordance with the present invention. The array 210 of the present invention may comprise

sections of alternating polarity along its length, as illustrated by the + sign on the elements 212 and - sign on the elements 214, separated by a transition zone 213. For typical magnetic pavement marking applications, the polarity alternates about every meter. The magnetic pavement elements 212, 214 in the illustrated embodiment have a height of about 0.25 millimeters to about 1.0 millimeters (0.010 to 0.040 inches), but less than 3 millimeters (0.118 inches). It will be understood that elements having other heights may be used if desired.

The array 210 comprises rows and columns of magnetic pavement elements 212, 214 preferably spaced apart by a distance of about 250 micrometers to about 5 millimeters, although spacing between the magnetic pavement elements can be as close as possible without interfering with conformabilty of the array. The planar dimension or width of the magnetic pavement elements is typically about 3 millimeters to about 10 millimeters, but elements having other widths may be used in accordance with the invention. The spacing of the magnetic pavement elements 212, 214 in the array 210 will vary depending on the height of the magnetic pavement elements and the particular application for which the magnetic pavement elements are to be used.

Retroreflective Magnetic Pavement Markers

The magnetic pavement markers of the present invention may be coated with retroreflective beads by a variety of techniques, such as disclosed in U.S. Patent No. 4,988,541. Suitable bead bond material for adhering the beads may be either a thermoplastic or a thermoset polymeric binder. One such binder is vinyl based thermoplastic resin, including a white pigment, as described in U.S. Patent No. 4,117,192. Other

suitable bead bond materials include two-part polyurethane formed by reacting polycaprolactone diols and triols with derivatives of hexamethylene diisocyanate; epoxy based resins as described in U.S. Patent No. 4,248,932, 3,436,359, and 3,580,887; and blocked polyurethane compositions as described in U.S. Patent No. 4,530,859. Other suitable bead bond materials are polyurethane compositions comprising a moisture activated curing agent and a polyisocyanate prepolymer. The moisture activated curing agent is preferably an oxalolidene ring, such as described in U.S. Patent No. 4,381,388.

Particles such as retroreflective beads suitable for use in the process include glass beads formed of glass materials having indices of refraction (n) from about 1.5 to about 2.26, and more preferably from about 1.5 to about 1.9. As is well known in the art, glass beads of material having an index of refraction of about 1.5 are less costly and more scratch and chip resistant than glass beads of material having an index of refraction of from about 1.75 to about 2.26. However, the cheaper, more durable glass beads are less effective retroreflectors. In one embodiment, the glass beads may include a silver or other specular reflective metallic or dielectric coating. The non-embedded portion of the silver coat is subsequently removed to provide a highly effective retroreflector. In another embodiment, beads having a hemispheric coating of a specular reflective metal, such as silver, are applied to the liquid bead bond layer. Because the beads are randomly oriented when applied, a fraction of the beads become embedded in a orientation which is effective for retroreflection. Generally, the effectively oriented beads have the

uncoated surface exposed and the silver coated surface embedded.

Preferred retroreflector beads are disclosed in U.S. Patent No. 4,564,556 and U.S. Patent No. 4,758,469. These beads are described generally as solid, transparent, non-vitreous, ceramic spheroids comprising at least one crystalline phase comprised of at least one metal oxide. These beads may also have an amorphous phase such as silica. The term non-vitreous means that it is not been derived from a melt or mixture of raw materials brought to liquid state at high temperature, like glass. These spheroids are very resistant to scratching and chipping, being quite hard (e.g., above 700 Knoop) and can be made with a relatively high index of refraction (ranging between 1.4 and 2.6). Examples of the compositions of these beads are zirconia-alumina-silica and zirconia-silica.

The retroreflector beads preferably have a diameter compatible with the size, shape, spacing and geometry of the magnetic pavement markers present upon the base sheet. For the earlier described base sheet 100, beads of 50-350 micrometers diameter may be suitably employed. Other factors affecting bead size are the number of rows of beads desired to be available to vehicle headlights. At an angle of about 2 - 3 degrees from the base sheet 100, only about 380 micrometers of side surface is visible. Thus, only about 1 row of 300 micrometer beads is visible, or about 2 rows of 225 micrometer beads.

<u>Binder Materials for Conformable Magnetic Layers</u>

In one embodiment of the present invention, conformable magnetic pavement elements are formed by dispersing a plurality of magnetic particles in a binder. A sufficient amount of magnetic particles are

present to provide a magnetic signal through the traffic-bearing structure to a sensor. Typically magnetic particles are non-spherical.

In some organic binder embodiments, for example when the organic binder comprises non-crosslinked elastomeric precursors (see for example U.S. Patent No. 4,490,432), traditional rubber processing methods preferably are used to produce the conformable magnetic layer, such as a heavy duty, batch or continuous, rubber kneading machine, such as a Banbury mixer or twin screw extruder.

"Elastomer precursor" is used herein to describe a polymer which can be crosslinked, vulcanized, or cured to form an elastomer. An "elastomer" is a material that can be stretched, to at least about twice its original dimensions without rupture and upon release of the stretching force rapidly returns to substantially its original dimensions. Illustrative examples of useful elastomer precursors include acrylonitrile-butadiene polymers, neoprene, polyacrylates, natural rubber, and styrene-butadiene polymers. Extender resins, preferably halogenated polymers such as chlorinated paraffins, but also hydrocarbon resins, polystyrenes or polycyclodienes, are preferably included with the non-crosslinked elastomer precursor ingredients, and are miscible with, or form a single phase with, the elastomer precursor ingredients. The extender resins preferably account for at least 20 weight of the organic components in a conformable layer when using this binder.

Useful thermoplastic reinforcing polymers are known in the pavement marking art (e.g., polyolefins, vinyl copolymers, polyethers, polyacrylates, styrene-

acrylonitrile copolymers, polyesters, polyurethanes and cellulose derivatives).

In other embodiments of the invention, the conformance layer has two primary components: a ductile thermoplastic polymer and a nonreinforcing magnetic mineral particulate. Preferably, the thermoplastic polymer is a polyolefin. These binders are described generally in U.S. Patent No. 5,194,113.

<u>Magnetic Particles</u>

The most likely choice of magnetic material is a composite of particles of a permanent magnetic material dispersed in a matrix of an organic binder. Many types of magnetic particles capable of being remanently magnetized are known to those familiar with the magnetic materials art.

The major axis length of such particles (defined as the maximum length in any direction) suitable for use in this invention ranges from about 1 millimeter down to about 10 nanometers. The preferred range is from about 200 micrometers down to about 0.1 micrometer. The saturation magnetization of the magnetic particles can range from about 10 to about 250 emu/g (electromagnetic units/gram), and is preferably greater than 50 emu/g. The coercivity of such particles can range from about 100 to about 20,000 oersteds, more preferably ranging from about 200 to about 5000 oersteds. Particles with coercivities less than about 200 oersteds are too easily accidentally demagnetized, while particles with coercivities greater than 5000 oersteds require relatively expensive equipment to magnetize fully.

One class of high-performance permanent magnet particles are the rare earth-metal alloy type materials. Examples of the incorporation of such

particles into a polymeric binder include U.S. Patent No. 4,497,722, which describes the use of samarium-cobalt alloy particles, and European Patent Application No. 260,870, which describes the use of neodymium-iron-boron alloy particles. Such particles are not the most preferred for this application, because the alloys are relatively costly; the alloys may experience excessive corrosion under conditions of prolonged outdoor exposure; and the coercivity of such alloys is typically greater than 5000 oersteds.

Many other types of metal or metal-alloy permanent magnet particles could be used, but are not the most preferred. They include Alnico (aluminum-nickel-cobalt-iron alloy), iron, iron-carbon, iron-cobalt, iron-cobalt-chromium, iron-cobalt-molybdenum, iron-cobalt-vanadium, copper-nickel-iron, manganese-bismuth, manganese-aluminum, and cobalt-platinum alloys.

Other magnetic materials are of the class of stable magnetic oxide materials known as the magnetic ferrites. One particularly preferred material is the hexagonal phase of the magnetoplumbite structure commonly known as barium hexaferrite, which is generally produced as flat hexagonal platelets. Strontium and lead can substitute in part or completely for the barium, and many other elements can partially substitute for the iron. Thus strontium hexaferrite is also a preferred material. Another class of preferred materials is the cubic ferrites, which are sometimes produced as cubic particles, but more often as elongated needle-like, or acicular, particles. Examples include magnetite (Fe_3O_4), magnemite or gamma ferric oxide (gamma-Fe_2O_3), intermediates of these two compounds, and cobalt-substituted modifications of the two compounds or of their intermediates. All of these

magnetic ferrites are produced in large quantities at relatively low cost and are stable under conditions of prolonged outdoor exposure. Their coercivities fall in the most preferred range of 200 to 5000 oersteds.

Chromium dioxide is another alternate material which may be useful as a magnetic particle in the invention due to its low Curie temperature, which facilitates thermoremanent magnetization methods.

The magnetic particles are generally dispersed in the polymeric matrix at a high loading. The magnetic particles constitute at least 1 volume percent of the magnetic layer, while it is difficult to include particles in an amount constituting more than about 75 volume percent of the material. Preferably, the magnetic pavement markers have a binder comprising at least 30 volume percent of magnetic particles. A preferred loading range would be about 30 to 60 volume percent, more preferably from about 45 to about 60 volume percent. To obtain the highest remanent magnetization, the particles preferably are substantially domain-size, anisotropic particles, and there preferably is substantially parallel alignment of preferred magnetic axes of a sufficient number of the particles so as to make the magnet material itself anisotropic.

Ferrites, especially barium, lead, and strontium ferrites, generally in a roughly plate-like form having preferred magnetic axes perpendicular to the general planes of the plates, are preferred as the particulate materials. However, other materials having permanent magnetic properties, such as iron oxide particles or such as particles of manganese-bismuth or iron protected against oxidation, can also be used.

As is known in the art and referred to above, the orientation of the magnetic particles may be

optimized by physically orienting (e.g. calendering) the particles.

For an exemplary array of magnetic pavement elements having a width of approximately 10 cm, and an average magnetic thickness layer of about 0.1 cm, the magnetic field is about 10 gauss at the surface of the article, 5 gauss at a distance of about 5 cm, 2 gauss at a distance of about 10 cm, and 1 gauss at a distance of about 15 cm. Thus, if the array were underlaid about 10 cm beneath a traffic-bearing surface, the magnetic field strength at the traffic-bearing surface would be approximately 2 gauss, which is believed to be sufficient to be detected by a sensor. Of course, stronger or weaker magnetic fields may also be produced by the array of magnetic pavement elements, depending on the materials and processes used to make the article.

The array of magnetic pavement markers of the present invention may be applied to the pavement surface either manually, or by a machine. The magnetic pavement markers of the present invention may be installed as part of a pavement surface using any one of a variety of apparatus, such as a manual dispenser, "behind a truck" types of dispensers, and "built into a truck" types of dispensers. For example, U.S. Patent No. 4,030,958 discloses a suitable behind a truck type dispenser for applying the articles of the invention in the form of adhesive-backed tapes to a surface and U.S. Patent No. 4,623,280 discloses a manual-tape applicator.

Guidance Systems

The invention also provides a system for guiding vehicles or mobile objects 222 traveling on a roadway 224, through a warehouse, and the like, general

illustrated in Figure 12. The array of magnetic pavement markers 226 is applied to the pavement surface 224 as discussed above. The array of magnetic pavement markers 226 can then be detected by a sensor system 228 on a vehicle 222 which drives over the pavement surface 224. A typical sensor system 228 includes a sensor device and a guidance device.

A number of sensors and transducers are available to convert the magnetic signal from the magnetic pavement markers of the invention into an electrical signal suitable for further processing. Illustrative examples of such sensors include flux-gate magnetometers, Hall effect sensors, and solid-state magnetoresistive (MR) sensors.

A potential problem exists in distinguishing the guidance signal from magnetic "noise" produced by steel reinforcing bars, other vehicles, and the like. If the inventive magnetic pavement markers are magnetized in a regular alternating pattern or in some "unique" pattern, the magnetic signal will then be periodic with a frequency proportional to the vehicle's speed. Modern signal processing techniques can then be used to extract the signal at a known frequency from the noise.

Magnetic sensors 228 attached to the vehicle 222 may determine the field in one, two, or all three directions. The signal from one sensor or a mathematical combination of two or three field components may be used to compute a signal that can be related to lateral distance of a vehicle 222 from the inventive articles.

By magnetizing the strip in a more complicated pattern, additional information can be encoded. For example, information about the direction and radius of an upcoming curve in the road or about

the slope of an approaching upgrade or downgrade could be used for feed-forward control of the lateral position and speed of the vehicle. As part of a vehicle navigation system, location codes could be given. Illustrative examples of indicating means include at least one horn, gauge, whistle, electrical stimulation, LCD, CRT, light, combination of these, and the like. One or more indicating means may be desired in a particular situation.

Conformable Carrier Webs

Conformability of carrier web can be evaluated in several ways. One simple way is to press a layer or sheet of the material by hand against a complex, rough or textured surface, such as a concrete block or asphalt composite pavement, remove, and observe the degree to which surface roughness and features are replicated in the layer or sheet. The conformable carrier web of this invention will conform to complex shapes and rough surfaces.

Elastic recovery is the tendency of a layer or sheet to return to its original shape after being deformed. Delayed elastic recovery can be observed by noting the tendency of the replicated roughness to disappear over time. A simple test for delayed elastic recovery is to use a blunt instrument to indent the carrier web. The ease with which an impression can be made and the permanence of the impression may be used to form rough comparative judgments about the conformance properties of the material used to form the sheet or layer.

Conformable carrier webs of this invention must be capable of being deformed under reasonable forces in order to take on the shape of the road surface irregularities and thereby to allow formation

of a good bond to the road surface. By reasonable forces is meant that after application of the carrier web to a road surface and rolling over the applied, flat marking sheet with a suitable tamping means, the carrier web conforms to the road surface. In such an application, the tamped carrier web substantially replicates the surface texture of the road. The suitable tamping means should not be excessively unwieldy. For prior art preformed pavement marking tapes, a tamping cart with a load (total weight about 250 lbs. (115 kg)) has commonly been employed in the application of marking tapes.

Another test for conformability is available through the following sequence of steps: 1. A test strip about 2.54 centimeters (1 inch) wide and about 10.16 centimeters (4 inches) long is pulled (i.e., deformed or strained) in a tensile strength apparatus at a rate of about 30.5 centimeters/minute (12 inches/minute) until it is strained to about 105% of original sample length (elongation of about 0.51 centimeters). 2. The pull is reversed and the machine returned to its starting point at a rate of about 30.5 centimeters/minute, causing a complete release of the tensile stress in the sample. 3. The strain at which a resisting force is first observed on the second pull (i.e. when the sample again becomes taut) is observed. The strain at which resistance is first observed on the second pull, divided by the first strain is defined as inelastic deformation (ID). In the present embodiment, strain is measured as the distance until the sample is taut is divided by the original elongation of 0.51 centimeters. A perfectly elastic material would have 0% ID, i.e., it would return to its original length. Metals approach 90% ID, but yield only at very undesirably high tensile stresses. Preferably, the

force required to achieve 5% strain (i.e., deformation) in a base sheet (initial thickness typically about 250 micrometers) is less than 25 lbs. per inch of sample width (44 Newtons/cm of sample width) and more preferably less than 10 lbs. per inch (18 NT per cm).

Unload energy is also a significant factor in determining the conformability of a carrier web for use in the present invention. The unload energy is defined as the energy remaining in the memory portion of an elongated material. Materials with lower unload energies should be more conformable.

Conformable composite materials of this invention combine a low unload energy of less than 1.25 grams/centimeter (0.7 pounds/inch) and an ID of greater than about 10%, preferably greater than 20%, more preferably not less than 30% at 25°C.

Example

Several strips of 25.4 mm wide (1 inch) and 1.5 millimeters (0.060 inches) thick Plastiform™ magnetic tape with a pressure sensitive adhesive on one side protected with a release liner (available from Arnold Engineering Company of Norfolk, Nebraska) were passed through the gap of a permanent magnet to magnetize the strips in one direction perpendicularly through the plane of the strip. Some of the strips were magnetized with the North pole on the non-adhesive coated side of the strip and some with the North pole on the adhesive coated side. The strips were then cut longitudinally to a width of about 12.7 mm (0.5 inch) using scissors and then again into about 12.7 mm (0.5 inch) square chips of Plastiform™ on adhesive and release liner. The release liner was removed from the chip and the squares were adhered to a piece of Reemay 2410 nonwoven scrim (available from Reemay, Inc.

located in Old Hickory, Tennessee) in an array 5 chips wide with a spacing of about 6.35 mm (0.25 inches) between each square. The array for this prototype was approximately 10.16 cm (4 inches) in width and about 22.86 cm (9 inches) in length. About 15.24 cm (6 inches) of the array was arranged so that the North pole of the magnetic chips was up and the remaining 7.62 centimeter (3 inches) was arranged so that the North side was down (i.e., toward the scrim). The sheet was run through a hand laminator to improve the bond between the pressure sensitive adhesive on the bottom of the magnetic chips and the scrim to yield an array of magnetic elements interconnected by a carrier web (i.e., the scrim).

A 0.127 millimeters (0.005 inches) thick layer of PM-7701 pressure sensitive adhesive (available from Minnesota Mining and Manufacturing Company) on a release liner (a rubber resin pressure sensitive adhesive commonly used for pavement marking tape applications) was laminated to the bottom of the scrim.

The prototype (or one without the layer of PM7701) could be useful for underlaying beneath the top surface of a roadway during its construction to provide a magnetic signal. Also, the array of magnetic chips could be mounted to the surface of a roadway. The nonwoven scrim or web provides a convenient low cost carrier for the magnetic chips. The discrete nature of the chips, rather than a continuous sheet, allows some movement of the chips relative to one another to accommodate roughness of the road surface, or, in the case of an underlay installation, movement during road compaction, in a way that would not be possible with a continuous sheet of non-conformable magnetic material. This feature also allows some movement to accommodate

thermal expansion and contraction and flexural stresses in a road during use.

In this example, a polymeric Plastiform™ magnet was used. Ceramic, metal or other magnets could also be employed. Other deformable or conformable carrier webs or scrims could be used as an alternate to the Reemay scrim. Conformable base sheets used in pavement marking tape conformance layers could be useful.

A portion of the conformable mosaic magnetic pavement marking example prepared above was cut to a size of about 2 by 9 piece array with a magnetic transition such that 4 rows of chips had magnetic south facing up and 5 rows had magnetic north facing up from the plane of the sheet. The liner was stripped from the lower adhesive layer and the adhesive side of the article was laminated to a piece of asphalt pavement and pressed in place by hand using a rubber roller. While the individual magnetic pieces did not significantly conform to the roughness of the asphalt, the sheet as a whole adapted itself to accommodate the surface roughness.

A Magnaprobe (small freely rotating bar magnet suspended in a gimbal mounting - available from Cochranes of Oxford Ltd., Leafield, Oxford OX85NT, England) was passed over the conformable mosaic magnetic pavement marking attached to the asphalt. The freely rotating magnet reversed its direction of orientation as it was passed over the boundary defining the change in direction (north up / south up) in the magnetic signal in the marking.

Patents and patent applications cited herein, including those cited in the Background, are incorporated by reference in their entirety. It will be apparent to those skilled in the art that many changes

can be made in the embodiments described above without departing from the scope of the invention. Thus, the scope of the present invention should not be limited to the methods and structures described herein, but only to methods and structures described by the language of the claims and the equivalents thereto.